

# **Case Study on Sustainability Criteria for Plastics Design, from a Chemicals Perspective: Flooring**

## **Healthy Building Network**

### **Introduction**

#### **Purpose of case study**

Plastic production has increased exponentially over the last 65 years, reaching 448 million tons in 2015.<sup>1</sup> Half of all plastics on earth today were made in the last 15 years.<sup>2</sup> Behind packaging, the building and construction industry is the second largest consumer of plastics, comprising 16% of global plastic production.<sup>3</sup>

The goal of this case study is to build on the findings from the recent OECD report “Considerations and Criteria for Sustainable Plastics from a Chemical Perspective”<sup>4</sup> and explore the human health and environmental impacts of chemicals in plastic materials in the building and construction sector using flooring as an example. By evaluating selected plastic flooring products, we are exploring how the selection of base plastics and associated chemical additives impacts the material life cycle with an eye to designing and managing materials, products, and processes for safety and sustainability, consistent with the OECD Policy Principles for Sustainable Materials Management (Text box 1).<sup>5</sup> Our research focuses on opportunities to reduce exposures to hazardous chemicals for fenceline communities, building occupants, and workers during manufacturing, installation, use, and end of life. For the purpose of this case study we define hazardous chemicals as Substances of Very High Concern for REACH (SVHC) or those on the ChemSec Substitute it Now List (SIN) unless otherwise noted.<sup>6,7</sup>

#### **Text box 1: OECD Policy Principles for Sustainable Materials Management<sup>5</sup>:**

1. Preserve natural capital
2. Design and manage materials, products, and processes for safety and sustainability from a life-cycle perspective
3. Use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes
4. Engage all parts of society to take active, ethically-based responsibility for achieving sustainable outcomes

This case study will not address all elements critical to sustainable production, which include cost, performance, availability, consideration of non-plastic alternatives, and social and environmental justice. Nor does it include full life-cycle analysis or a full review of regulatory restrictions. Cleaning and other maintenance products used over the product life cycle could have varying chemical impacts for different product types but are beyond the scope of this case study. These are important topics and should be considered during materials selection.

#### **Flooring Landscape**

Flooring covers a significant portion of the interior surface area of a building. In the United States alone, floor covering sales surpassed \$27 billion USD (almost 23 billion euros) and 23.5 billion square feet in 2019.<sup>8</sup> A wide range of materials can be used as floor coverings, and each can have human and

environmental health impacts at various stages of the product life cycle. Common materials used for floor coverings include wood, linoleum, ceramics, rubber, and plastic. Resilient plastic products account for over 22% of all floor coverings sold in the United States.<sup>9</sup> Polyvinyl chloride (PVC), also known as vinyl flooring, is by far the most common. Other plastics that can be used in floor coverings include ethylene vinyl acetate, polyolefins, polyesters, thermoplastic polyurethane, and acrylics.<sup>10</sup>

Frequency of replacement depends on the type of flooring and the application. Reported life expectancies for flooring products range from 5-100 years, with plastic flooring life expectancy typically in the range of 5-25 years.<sup>11</sup> Changing aesthetic desires or other factors can lead to flooring replacement before the end of the product's useful life.

### **Design Requirements for Flooring**

Flooring materials must meet a myriad of performance and aesthetic requirements from the user perspective. These include a look and feel to match the application (residential, commercial, etc), durability, acoustics, water resistance, and ease of installation and maintenance. Additional design requirements that are beneficial from a sustainability and circularity perspective are eliminating or minimizing the use or generation of hazardous chemicals and pollution throughout the product's life, incorporating recycled content, and design for reuse and recyclability.

### **Product Types Selected for Case Study**

Traditionally, PVC has dominated the plastic flooring market, but while the global market for PVC flooring continues to expand, new plastic alternatives to traditional PVC flooring are emerging.<sup>12</sup> For this reason, this case study considers three options:

1. Vinyl sheet and vinyl tile. This is a PVC based homogeneous resilient flooring installed with an adhesive.
2. Wood plastic composite (WPC). WPC is a multilayer resilient flooring which contains a PVC wear layer and a rigid expanded or foamed core that is commonly composed of PVC.<sup>13,14</sup> Contrary to what the name implies, WPC floors may not contain any wood or cellulose-based fillers.<sup>15</sup> They are generally manufactured as interlocking tiles with a tongue and groove installation system.
3. Polyethylene terephthalate (PET). While numerous types of polymers can be used to represent a non-PVC, non-elastomeric resilient flooring, for this case study, we will use polyester-based flooring products and use polyethylene terephthalate (PET) installed with an adhesive as a specific example.

Plastic flooring products typically contain about 11-35% by weight of the polymer itself, the remainder being fillers and additives. Vinyl sheet and tile flooring is composed of PVC and fillers like calcium carbonate. Because it needs to be flexible, durable, and aesthetically pleasing, it requires the addition of plasticizers, stabilizers, and other additives like pigments. Many vinyl flooring products also have a polyurethane acrylic finish for durability and abrasion resistance. Some finishes may additionally contain stain repellent additives like per- and polyfluoroalkyl substances (PFAS).<sup>16</sup>

WPC flooring contains a layer of PVC flooring on top of a rigid polymeric core. Both layers are similar in composition to vinyl sheet or tile, but the core is typically not plasticized and requires a blowing agent (a blowing agent is a substance that creates a cellular structure in the resin using a foaming process). The

core is layered on top of a cork underlayment, bound together with polyurethane, for thermal and acoustic insulation. The layers adhere to one another with adhesives.

PET resilient flooring products are also composed mostly of polymeric binders, fillers, pigments, and other additives and have a similar finish as vinyl flooring. The primary difference, besides the polymer itself, is that PET flooring does not require a plasticizer.

Product content and process chemistry information provided throughout this case study is based on Common Product research unless otherwise noted. Details on the typical chemical content, the functional roles of that content, and percentage in the product is provided in Appendix A for each flooring type. This same product information and original source documentation is also available in the Common Products section of the Pharos database.<sup>17</sup>

## **Chemical Considerations Throughout the Life Cycle**

Plastic flooring products can have human and environmental health impacts at every stage of the product life cycle, including production, installation, use, and disposal or recycling. Different plastics use different feedstocks, monomers, and catalysts and require different functional additives that may result in different exposures to a variety of substances. The type of polymer and additives can also impact the recyclability of flooring materials and associated chemical releases at end of life. This section of the case study outlines some of these differences.

### **Production**

#### ***Base Polymer Source Materials***

The primary chemical inputs for the manufacture of PVC and PET are included in Table 1 below.

#### PVC - chlorine production

The primary concerns with vinyl flooring production relate to its reliance on chlorine chemistry. The plastic component of these products (including vinyl tile, vinyl sheet, and WPC) is polyvinyl chloride (PVC). The production of PVC starts with the production of chlorine gas. Production of chlorine gas relies on one of four different technologies. Older technologies utilize mercury cells or asbestos diaphragms. Newer technologies either use per- and polyfluoroalkyl substance (PFAS) diaphragms or PFAS-coated membranes. While most PVC production utilizes the latter two technologies, all four methods of production are still widespread. All of these technologies rely on hazardous chemicals, with mercury and asbestos being on the SIN list and some of the chemicals in the PFAS class identified as SVHCs, with many more PFAS chemicals unstudied for health impacts.<sup>18</sup>

#### PVC- VCM production

Vinyl chloride monomer (VCM) used in PVC synthesis is produced via either an acetylene or ethylene route. The former route employs coal and mercury-based catalysts and the latter uses ethylene from natural gas or crude oil and generates ethylene dichloride (EDC) as an intermediate in the production of VCM. Vinyl chloride itself is listed as carcinogenic on the SVHC list, and both routes have downsides with mercury as a reproductive toxicant on the SIN List and EDC as a carcinogen listed as a SVHC.<sup>19</sup>

20

There are known to be a range of hazardous chlorinated emissions through the manufacturing of chlorine to VCM to PVC. Different plants report different levels of hazardous emissions for a given production output.<sup>21</sup> The extent to which hazardous emission can be and will be controlled should be considered in the design process because these emissions can directly impact fence-line communities and the broader environment.

#### PET production

No SVHCs were identified in the process chemicals for PET. The intermediate ethylene oxide and catalyst antimony trioxide are on the SIN list.<sup>22</sup> There is limited transparency around the specific polyesters used for flooring and the chemicals used to produce them, but within polyester polymers there is a range of possible chemistries. For example, a patent identifies dibutyltin bis-lauryl mercaptide as a catalyst for polyester polymers used in flooring and alternative process chemicals such as 1,3-propanediol that may avoid ethylene oxide for particular manufacturing routes.<sup>23</sup> 1,3-propanediol may also be manufactured from renewable, bio-based content.<sup>24</sup>

Table 1. Chemicals used in production of base polymer source materials. This table and subsequent tables in this report include the chemical inputs, emissions (where known), and possible exposure scenarios. **Chemicals in red and bolded are identified as Substances of Very High Concern (SVHC) for REACH.** Chemicals in red and underlined are on the SIN list.

	PVC (Used to make vinyl sheet/tile and WPC)	PET
Chemical Inputs		
Primary Chemicals	Chlorine Ethylene Hydrogen	P-xylene Methanol Ethylene
Intermediates	Hydrochloric Acid <b>Ethylene Dichloride</b>	Acetic Acid <u>Ethylene Oxide</u> Ethylene Glycol Terephthalic Acid Dimethyl Terephthalate
Monomers	<u>Vinyl Chloride</u>	Bis(2-hydroxyethyl) terephthalate
Catalysts/process chemicals for different stages	<u>Mercury</u> <u>Asbestos</u> <b>PFAS diaphragm or membrane*</b>	Zinc Oxide <u>Antimony Trioxide</u> Dibutyltin bis-lauryl mercaptide
Chemical Outputs/Emission	Organochlorine chemicals including: <b>Ethylene Dichloride</b> <u>Vinyl Chloride</u>	<i>Data Gap</i>

	Dioxins <u>Carbon Tetrachloride</u> <u>Chloroform</u> <u>HCBD</u> PCBs	
Likely Exposure Scenarios	Occupational  Human and environmental via environmental release during manufacture	Occupational  Human and environmental via environmental release during manufacture

\*Some chemicals within the PFAS class are known to be hazardous and are considered SVHCs  
Sources for table<sup>25</sup>

When choosing the base polymer for a flooring product, one should consider how the alternatives compare in terms of volume of hazardous chemicals, the availability of alternative synthesis routes or manufacturing processes that avoid or reduce hazardous chemicals, and the data gaps that exist. As outlined above, multiple routes of synthesis or chemical inputs exist for PVC and PET, so understanding the impacts of the plastic material used depends on understanding the supply chain for the chemical inputs.

Less information is available on the upstream process chemistry of PVC-free alternatives, but one advantage of polyester – and PVC-free polymers generally – is the range of chemistry options that can allow for choosing inherently safer chemistry.

### ***Product Manufacture***

Following the production of the base polymer, these materials are combined with a range of additives to manufacture the flooring itself. Table 2 summarizes the primary differences in additives used between the product types and likely exposure scenarios during product manufacturing.

Table 2. Chemicals used during product manufacture. **Chemicals in red and bolded are identified as Substances of Very High Concern (SVHC) for REACH.** Chemicals in red and underlined are on the SIN list.

	Vinyl Sheet/Tile	WPC	PET
Plasticizers	<b><u>Orthophthalates*</u></b> Terephthalates Dibenzoates	Same as vinyl sheet/tile	N/A
Stabilizers (UV or heat stabilizers)	<b><u>Lead-based**</u></b> <b><u>Cadmium-based</u></b> Calcium-Zinc Barium-Zinc	Same as vinyl sheet/tile	Pentaerythritol tetrakis(3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate)^

Blowing Agent	N/A	Azodicarbonamide Sodium bicarbonate	N/A
Recycled Plastic (hazardous chemicals in recycled plastics that may be used in these flooring products)	<b>Orthophthalates*</b> <b>Lead</b> <b>Cadmium</b> <b>PCBs</b> <b>Nonylphenol</b> <b>phosphite (3:1)</b>	Same as vinyl sheet/tile	UV stabilizers  Biodegradation additives - Ex. <u>Cobalt-</u> based salt  <u>Antimony trioxide</u>
Likely Exposure Scenarios	Occupational  Human and environmental via environmental release during manufacture	Occupational  Human and environmental via environmental release during manufacture	Occupational  Human and environmental via environmental release during manufacture

\*Several chemicals within the orthophthalate class are known to be hazardous and are considered SVHCs.

Orthophthalates have been phased out of use in certain markets and regions.

\*\*Lead and cadmium based stabilizers have been phased out of many regions.

^Many different stabilizers may be used. This is an example of one chemical that is used in PVC-free resilient flooring generally and can be used with polyesters.

Sources for table<sup>26</sup>

### PVC intentional additives

The primary additives that may be of concern in vinyl flooring are plasticizers and stabilizers.

Orthophthalate plasticizers and lead- and cadmium-based stabilizers are SVHCs. These hazardous additives are not typically regulated for use in flooring. In many regions orthophthalates and lead-based stabilizers have been phased out in favor of chemicals believed to be of lower hazard, but may still be used in some products.<sup>27</sup> In the EU, high molecular weight orthophthalates (those with 7 or more carbons in their backbone) are replacing low molecular weight orthophthalates, in PVC. Consequently, orthophthalates could potentially still be used in flooring products.<sup>28</sup> These higher molecular weight orthophthalates also have human health concerns. For example, diisononyl phthalate is also a SVHC. When selecting plasticizers for PVC flooring, orthophthalates can and should be avoided. Likewise, industry data suggest that lead- and cadmium-based stabilizers have essentially been phased out in North America; safer alternatives such as calcium- and zinc-based stabilizers are available and should be used.<sup>29</sup>

### WPC intentional additives

The production concerns that apply to vinyl flooring also extend to multi-layer resilient, wood plastic composite (WPC) flooring. WPC also uses about three times the quantity of PVC as standard vinyl flooring for a given area.<sup>30</sup> This additional PVC amplifies the concerns associated with the production of vinyl flooring by increasing the amount of vinyl used for a given surface area of flooring. The WPC core also requires a blowing agent. The blowing agent identified in our research, azodicarbonamide, is considered an SVHC for respiratory sensitising properties.

TEXT BOX: Safer alternatives to orthophthalates. Safer alternatives to orthophthalates are available. Resources like ChemFORWARD provide comprehensive chemical hazard assessments of alternatives to orthophthalate plasticizers to help users find and adopt safer alternatives to a number of different plastic additives.<sup>31</sup>

#### PET intentional additives

No SVHCs or SIN list chemicals were identified as common additives in PET resilient flooring.

#### Vinyl sheet/tile and WPC unintentional content from recycled feedstocks

Some vinyl flooring incorporates recycled PVC content.<sup>32</sup> Legacy hazardous chemicals can be present in recycled PVC unintentionally adding orthophthalates and hazardous stabilizers. Non-flooring sources of recycled PVC can introduce additional hazardous content such as PCBs.<sup>33</sup> Recycled PVC should be avoided unless manufacturers can verify that a closed-loop recycling process is used that eliminates the introduction of hazardous legacy chemicals into flooring products.

#### PET unintentional content from recycled feedstocks

Post-consumer PET bottles could be used in PET flooring, which seems to be the case for a recently announced but not yet commercially available flooring product.<sup>34</sup> One of the primary concerns with PET historically has been the use of antimony trioxide as a catalyst during production.<sup>35</sup> It is not known to what extent antimony trioxide may be present in PET flooring products from virgin PET, but products incorporating recycled content from plastic water bottles may introduce some residual catalyst. Another potential concern with recycled PET is the use of biodegradation additives in some plastic packaging which could impact future performance of a flooring product.<sup>36</sup> The specific recycled plastic to be used in a PET resilient flooring should be analyzed for potential hazardous content or content that could impact the performance of the flooring product.

### Use

#### ***Installation***

Vinyl sheet and tile and PET flooring are typically installed with an adhesive. WPC does not use adhesive, rather relies on a tongue-and-groove click tile installation. Some common hazardous chemicals found in typical flooring adhesives are summarized in Table 3 below. For vinyl sheet/tile or PET, installers using site applied adhesives (acrylic, epoxy, and polyurethane) may have more potential for exposure than factory applied adhesives (peel and stick). WPC has the potential to avoid these hazards during the installation phase by significantly reducing or eliminating the use of an adhesive, but there are trade-offs at other phases of the lifecycle.

Table 3. Chemical used in flooring adhesives. **Chemicals in red and bolded are identified as Substances of Very High Concern (SVHC) for REACH.** Chemicals in red and underlined are on the SIN list.

Type of Adhesive	SVHC or SIN List Chemical Content
Acrylic (Peel and Stick)	<u>Triphenyl phosphate</u> (stabilizer) - 0.5% <b>Octamethylcyclotetrasiloxane (D4)</b> (residual monomer in release paper) - <0.01%

Acrylic	<u>Distillates (Petroleum), Hydrotreated (Mild) Heavy Naphthenic (9CI) (defoamer)</u> - 0.2%
Epoxy	<b>4-Nonylphenol</b> (catalyst) - 2.0% <b>Bisphenol A</b> (monomer) - 5.5%
Polyurethane	<u>C13-C15 alkane</u> (solvent) - 5.0% <u>Dibutyltin dilaurate</u> (catalyst) - 0.6%

Sources for table<sup>37</sup>

### *Use as Installed*

#### Vinyl sheet/tile and WPC

The biggest use-phase exposure concerns for vinyl flooring come from plasticizers and stabilizers required for this type of plastic. As discussed above, historically, orthophthalate plasticizers and lead-based stabilizers, which have potential to migrate from the flooring and collect in dust, have been used. This can lead to exposure for building occupants. Of particular concern is the impact on young children, who are more vulnerable because they crawl on floors and often place their hands in their mouths.<sup>38</sup>

#### PET

Based on our research into product composition for PET flooring, there is minimal concern with respect to hazardous chemical exposures during the use phase. Residual monomers and catalysts, such as antimony trioxide, may be present in polymer resins, typically at less than 1000 ppm and 100 ppm by weight, respectively.<sup>39</sup>

Table 4. Chemicals present in flooring as used. **Chemicals in red and bolded are identified as Substances of Very High Concern (SVHC) for REACH.** Chemicals in red and underlined are on the SIN list.

	Vinyl Sheet/Tile, WPC	PET
Chemical inputs	<b>Orthophthalate Plasticizers<sup>a</sup></b> <b>Lead- and Cadmium-based stabilizers<sup>a</sup></b> <b>PCBs<sup>b</sup></b>	Residual <u>Antimony trioxide</u> catalyst <sup>c</sup>
Exposure considerations	Direct human via product  Human and environment via environmental releases from product.	Direct human via product  Human and environment via environmental releases from product.

<sup>a</sup> These have largely been phased out of North American and European markets but may still be present in virgin materials in other regions.

<sup>b</sup> May be introduced via recycled PVC feedstocks.

<sup>c</sup> Residual antimony trioxide is known to be present in PET water bottles, and may be present in PET flooring as well.<sup>40</sup>

### **End of Life**



Multiple fates are possible for flooring products at their end of life. They can be landfilled, incinerated, or recycled. Plastic flooring is not typically reused or recycled at its end of life.<sup>41</sup> Some manufacturers do have take-back programs for both PVC and PVC-free flooring; a small but increasing amount of plastic flooring is being recycled.<sup>42</sup> It is not clear how much of this is recycled back into new flooring.

### ***Landfill***

Landfill is the most common end of life for flooring. In the United Kingdom, for example, over 90% of flooring goes to landfill<sup>43</sup>. Fires in landfills or leaching can lead to chemical releases with few environmental controls.

### ***Incineration***

When PVC is incinerated, it releases chlorine gas that can contribute to the formation of dioxins.<sup>44</sup> The release of dioxins is a concern for waste-to-energy processes because they are considered to have high acute toxicity and reproductive toxicity<sup>45</sup>. Studies have demonstrated that dioxin formation is highly dependent on combustion conditions, and measures can be taken to minimize dioxin formation in incinerators.<sup>46</sup> Dioxin formation may be a larger problem for PVC that enters landfills, where fires are common and where combustion conditions cannot be controlled<sup>47</sup>. Incineration of PET does not generate dioxins but can still generate PAHs and other VOCs.<sup>48</sup>

### ***Recycling***

Plastics can be recycled through either a chemical or a mechanical process, both having limitations or drawbacks. Chemical recycling allows separation of additives and returns polymers to their original monomer form. Mechanical recycling is the less expensive option, but it does not allow for the separation of additives.

#### Vinyl sheet/tile

Mechanical recycling of PVC can lead to the incorporation of hazardous legacy chemicals into new products. Source separation and testing are key in the recycling process to avoid contamination from flooring or other types of feedstocks with hazardous legacy chemicals or contaminants.<sup>49</sup> This underscores the urgency to take steps towards a closed-loop recycling process for PVC flooring products that ensures new PVC flooring formulations do not get contaminated by feedstocks containing old PVC flooring formulations and other sources of PVC that may contain hazardous legacy chemicals. Chemical recycling of PVC can help avoid legacy contamination but can lead to the formation of dioxins.<sup>50</sup>

#### WPC

While WPC flooring has similar composition to traditional vinyl flooring, the additional layers that must be separated prior to recycling may make it more difficult to recycle. However, one source suggested that closed-loop recycling of WPC flooring may be possible.<sup>51</sup> The same potential for dioxin formation or the inclusion of hazardous legacy chemicals would exist as with vinyl sheet/tile flooring.

#### PET

Chemical recycling of PET can occur through a variety of mechanisms. One of the most common mechanisms is glycolysis, which relies on reagents with known and potential human health effects like ethylene glycol and propylene glycol (though neither is an SVHC or SIN List chemical).<sup>52,53</sup> It may also employ organometallic catalysts based on heavy metals.<sup>54</sup> In the mechanical recycling process, PET is

ground up and reprocessed through a melt extrusion into granules that can be used for a variety of purposes including aggregates in concrete mixes.<sup>55</sup>

## **Policy Considerations**

Regional regulations and voluntary industry programs can influence how products are made across the world. This section will explore examples of policies that resulted in hazardous chemicals reductions in the resilient flooring industry.

### Global regulations: e.g. Mercury in PVC manufacturing

As discussed above, mercury has historically been used in the manufacturing of PVC. One of the most well-known cases of mercury pollution occurred at a PVC plant in Minamata, Japan following World War II. The plant dumped mercury waste into the Minamata bay. By the 1990s, tens of thousands of people in the area were suffering from the chronic effects of mercury poisoning and over 1,000 died. The Minamata Convention, a new global agreement, entered into force in 2017. It aims to reduce the use of mercury catalysts in VCM production by half by the year 2020 against 2010 use. The Minamata Convention also bans the use of mercury in chlor-alkali production by 2025. As of September 2020, there were 85 ratifying parties to the convention, including China.<sup>56</sup> The United States has “accepted,” but not ratified, the Minamata Convention. As use of mercury cell technology decreases, the use of diaphragms or membranes coated with PFAS increases.<sup>57</sup>

### Federal regulations: e.g. Orthophthalate plasticizer restrictions in consumer products including flooring

Very few federal regulations exist banning the use of orthophthalates in flooring products. As early as 2005, federal regulations in the EU began limiting the use of orthophthalates in children's toys.<sup>58</sup> However, the same chemicals banned in children's products were still being used in consumer and commercial flooring products. The EU is one of the first governing agencies to expand restrictions on orthophthalates beyond children's products to other consumer products. In July 2020, restrictions under the EU's REACH legislation went into effect, restricting the use of four specific orthophthalates in consumer products, including flooring.<sup>59</sup>

### Advocacy campaigns e.g. those leading to retailer restrictions.

While federal regulations in the U.S. have not restricted the use of orthophthalates in flooring, successful campaigns by advocacy organizations such as Safer Chemicals Healthy Families' “Mind the Store Campaign” pressured retailers to reduce the sale of products containing hazardous chemicals including orthophthalates. Starting in 2015, retailers in the U.S. began to phase out the sale of flooring containing orthophthalates in their stores, including The Home Depot, Lowe's, Lumber Liquidators, Menards, Ace Hardware, and Floor & Decor.<sup>60</sup>

### Industry programs: e.g. material tracing take back

Barriers to recycling of plastic flooring materials include lack of infrastructure, technical challenges, lack of materials disclosure, and lack of incentives. These barriers result in a limited amount of recycling of plastic flooring. Some voluntary industry programs have been established to help facilitate more recycling. VinylPlus, a voluntary program of Europe's PVC industry, aims to increase the rate of recycling of PVC by engaging with recyclers, improving materials tracing, and defining best practices for

the industry through a program called Recovinyl.<sup>61</sup> In 2019, VinylPlus reported about 3,157 tonnes of flooring were recycled in Europe. While this is a 4.7% increase in PVC recycling overall compared to 2018, this is estimated to account for <1% of PVC flooring produced and sourced in Europe.<sup>62,63</sup>

## Conclusion

In this flooring case study, we explored how the selection of base plastics and associated chemical additives impacts the exposures to hazardous chemicals for fenceline communities, building occupants, and workers during manufacturing, installation, use, and end of life. We also discussed how these materials and additives impact the ability of those materials to contribute to a circular economy. Trade-offs exist at each stage of the product's life-cycle between vinyl sheet/tile, WPC and PET plastic flooring. Below is a summary of important criteria to consider when designing plastic resilient flooring to reduce the impacts on human health and the environment. These criteria broadly include considerations from OECD Policy Principles for Sustainable Materials Management: 1) Preserve natural capital; 2) Design and manage materials, products, and processes for safety and sustainability from a life-cycle perspective; and 3) Use the full diversity of policy instruments to stimulate and reinforce sustainable economic, environmental, and social outcomes.

1. **Chemical Hazards of Base Polymer and Source Materials:** Consider chemical hazards in the supply chain for the base polymers under consideration. Choose a plastic type based on inherently safer chemistry and look for safer process chemistry options within a plastic type, when they exist. Prioritize avoidance of hazardous chemicals where there is greatest potential for exposure. Consider choosing base polymers that minimize the need for additives, simplifying the makeup of the final product.
2. **Chemical Hazards of Additives/Additive Life Cycle:** Consider the chemical hazard of additives and potential impacts on workers, building occupants, and the broader environment. When data is available, consider life cycle impacts for the manufacture of additives. Design the product with circularity in mind, consider potential future regulations and emerging chemicals of concern that could impact the recyclability/reusability of the product at the end of life. Key additive considerations for plastic resilient flooring include:
  - **Plasticizers:** Avoid using a polymer that requires a plasticizer. If needed, avoid using orthophthalate plasticizers. Use alternatives that are fully disclosed, that meet performance requirements, and have been assessed for their hazard properties to ensure they are less hazardous.
  - **Stabilizers:** Avoid using a polymer that requires the use of hazardous stabilizers. If necessary, avoid the use of lead and cadmium-based stabilizers.
3. **Chemical Hazards During Use:** Consider the hazards associated with accessories needed for installation such as adhesives. Avoid hazardous additives that can migrate from the product into interior spaces over time.
4. **Options for Recycled Feedstocks without Hazardous Content:** Consider options for recycled feedstocks. Prefer recycled feedstocks that are from known sources and tested for common hazardous content to avoid introducing hazardous content into new products.
5. **Recyclability and Availability of Recycling Infrastructure:** Consider whether the material is recyclable at end of life and if a recycling infrastructure exists or is under development. Design for recyclability becomes meaningful only when it is practically implementable. Prefer plastics

that are recyclable and have effective collection and recycling infrastructure in place or partner with others to develop this infrastructure as part of the product development process. Increased reclamation and recycling of materials when a building is constructed, renovated, or demolished is needed in general. Efforts that generate content transparency about products can aid in understanding of product content at this stage and increase potential for effective recycling.

## Application of Criteria to Case Study

1. **Chemical Hazards of Base Polymer and Source Materials:** PVC is the most common base polymer used in resilient flooring. PVC manufacturing utilizes or releases several SVHCs (including ethylene dichloride) and SIN List chemicals (including carbon tetrachloride) in the production of the base material. Manufacturers of PVC have multiple synthesis routes to choose from both with the generation of chlorine gas and the generation of the vinyl chloride monomer. Manufacturers thus have an opportunity to evaluate and choose the route with the lowest hazard inputs and fewest hazardous emissions.

PET, manufacturing also utilizes some SIN List chemicals (including antimony trioxide). Alternatives catalysts exist, but do not appear to be commonly used. Manufacturers of PET have an opportunity to choose a fully assessed, less hazardous catalyst to replace antimony trioxide.

In addition to PVC and PET, other base polymers can be used in resilient flooring including polypropylene, ethylene vinyl acetate, polyester, and thermoplastic polyurethane. Different polymers may pose different concerns in terms of chemical hazards during the manufacturing process. Product manufacturers can compare all options to better understand the impacts and choose the best polymer for their product.

2. **Chemical Hazards of Additives/Additive Life Cycle:** Vinyl sheet flooring or tiles can contain several additives that are SVHCs (including lead and cadmium). The PVC industry indicates that these hazardous additives are no longer necessary because less hazardous alternatives are available. WPC flooring has the same product manufacturing concerns as PVC with the addition of required blowing agents, of which one is an SVHC (azodicarbonamide).

PET products do not use SVHCs or SIN list chemicals in the product manufacture stage, but could introduce hazardous chemicals (e.g. cobalt) via recycled content.

Manufacturers of resilient flooring can choose to use polymers that do not require the use of hazardous additives. If those additives are needed, manufacturers can choose alternative additives that are fully disclosed, that meet performance requirements, and have been assessed to ensure they are less hazardous.

3. **Chemical Hazards During Use:** Vinyl sheet/tile and PET typically require an adhesive for installation which can introduce SVHCs (including bisphenol A) and SIN List chemicals

(including dibutyltin dilaurate). Peel and stick adhesives avoid many of the hazardous chemicals commonly found in acrylic, epoxy, and polyurethane wet-applied adhesives.

WPC does not require adhesives, however, it can use three times the volume of PVC polymer per square meter as vinyl sheet or vinyl tile. This triples the impacts from the production and manufacture stage per square meter of flooring. This is an important trade off to consider.

An opportunity for innovation exists to design a product that can be mechanically installed, without adhesive, that reduces the amount of PVC in the product. This change could effectively reduce the volume of problematic chemicals used in production per square foot of coverage.

4. **Options for Recycled Feedstocks without Hazardous Content:** Recycling of vinyl flooring or WPC flooring can introduce legacy toxic chemicals such as orthophthalates and lead- and cadmium-based stabilizers into new products. Manufacturers can select recycled waste streams from known sources, with fully disclosed content, that have been tested and confirmed free of common hazardous contaminants.
5. **Recyclability and Availability of Recycling Infrastructure:** Plastic flooring is typically either landfilled or incinerated at the end of life. A small but increasing amount of plastic flooring is recycled. WPC in particular may be difficult to recycle due to the multiple layers of different materials used in the product. PET typically has fewer hazardous chemicals in the product, keeping the recycled content clean for future uses. Innovation is needed in this sector both from a product design perspective and a recycling perspective. Product manufacturers should design products with a circular economy in mind, by avoiding chemical additives, adhesives, or multilayered structures that reduce the value or recyclability of the product. Manufacturers can also participate in and support materials transparency, materials tracing, and engage with recyclers. In addition, policies supporting extended manufacturer responsibility programs could be implemented.

This paper focuses on comparing plastic resilient flooring products; however, additional flooring options are available in the marketplace such as ceramic tile, carpeting, and linoleum. Healthy Building Network has generated a Flooring Products Hazard Spectrum that places these products on a continuum of improvement based on the goal of hazard avoidance. Product types at the green end of the spectrum typically have lower human health and environmental concerns than those in the yellow or orange colors, while those at the red end of the spectrum should be avoided when possible (See Appendix B). In product design, innovation may require the consideration of vastly different materials versus making incremental improvements in chemistry for a particular type of product.

## Appendix A. Product Composition

A Common Product profile is a list of substances that are most commonly present in a product type as delivered to building sites. The profiles are not specific to any manufacturer. Although Common Products and the example formulations cited below are specific to product compositions available in North America, for the report above we discuss potential regional variations that may exist outside of this region.

### Luxury Vinyl Tile Common Product\*

Chemical	CASRN	% Weight Product	Function
Limestone	1317-65-3	63.7%	Filler
Polyvinyl chloride	9002-86-2	22.4%	Resin
Bis(2-ethylhexyl) terephthalate	6422-86-2	9.6%	Plasticizer
Epoxidized soybean oil	8013-07-8	1.4%	Stabilizer, Process Aid, Plasticizer
Quartz	14808-60-7	0.7%	Impurity
Zinc stearate	557-05-1	0.6%	Stabilizer
Magnesium aluminum hydroxide carbonate	11097-59-9	0.5%	Acid Absorber
Zeolites	1318-02-1	0.5%	Acid Absorber
Calcium stearate	1592-23-0	0.2%	Stabilizer
Titanium dioxide^	13463-67-7	0.2%	Pigment
UV cured finish	See Pharos for more details	0.3%	Finish

\*For a full list of sources used to generate this Common Product see Pharos. "Luxury Vinyl Tile (LVT)." Accessed September 18, 2020. <https://pharosproject.net/common-products/2077801>. Common Product research methodology is described in detail at <https://pharosproject.net/common-products/methodology>.  
^many other pigments may be used in specific products

## **Appendix A (cont.)**

### **Wood Plastic Composite Common Product**

To be added: <https://pharosproject.net/common-products/2203433>

### **PVC-free Resilient Flooring (Homogeneous) Common Product**

To be added: <https://pharosproject.net/common-products/2180586>

## Appendix B. Healthy Building Network Flooring Hazard Spectrum

Hazard spectrums organize Healthy Building Network's research, identifying practical attributes to look for when specifying safer products, and red-flagging products or chemicals to be avoided. Individual products can vary significantly in their health and environmental profiles; however, some types are generally better than others when it comes to the health of building occupants, installers, and the broader environment. HBN uses a simplified spectrum to rank different types of products within a product category. You can use it to benchmark your current practice and take a step up to healthier options. Products in green categories are typically the best options, whereas products at the bottom of the spectrum, in red, are to be avoided. Those in between provide intermediate options from a health hazard perspective.

The Flooring Products Hazard Spectrum encompasses a wide variety of flooring options, including resilient, ceramic tile, wood, and carpet. The spectrum excludes adhesives which may be required to install the products. Refer to the Flooring Installation Hazard Spectrum for guidance.

Linoleum	▼
Solid Wood Floors (pre-finished)	▼
Ceramic Tiles (made in the USA/lead-free with no CRT content)	▼
PVC-free Resilient Flooring	▼
Engineered Wood Floors (pre-finished)	▼
Solid Wood Floors (site-finished)	▼
Rubber or Rubber/Cork Floors (made without crumb rubber)	▼
Laminate	▼
Carpet (with no fly ash, no vinyl or polyurethane backing, and no PFAS)	▼
Engineered Wood Floors (site-finished)	▼
New Formulations of Vinyl Floors (phthalate-free)	▼
Ceramic Tiles (not made in the USA/presence of lead is unknown/CRT tiles)	▼
New Formulations of Vinyl Floors (with post-consumer recycled content)	▼
Traditional Vinyl Floors	▼
Rubber or Rubber/Cork Floors (made with crumb rubber)	▼
Carpet (containing fly ash, vinyl or polyurethane backing, and PFAS)	▼
Traditional Vinyl Floors (with post-consumer recycled content)	▼



<sup>1</sup> Parker, Laura. "The world's plastic pollution crisis explained." National Geographic. June 7, 2019. Accessed September 30, 2020. <https://www.nationalgeographic.com/environment/habitats/plastic-pollution/>

<sup>2</sup> *ibid*

<sup>3</sup> Parker, Laura. "We made plastic. We depend on it. Now we're drowning in it." National Geographic. June 7, 2019. Accessed September 30, 2020.

<https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/>

; Barron, Jacob. "The growing role of plastics in construction and building." Plastics Industry Association. January 20, 2016. Accessed September 30, 2020. <https://www.plasticsindustry.org/article/growing-role-plastics-construction-and-building>

<sup>4</sup> Organization for Economic Cooperation and Development (OECD). "Considerations and criteria for sustainable plastics from a chemicals perspective: Background paper 1." May 29, 2018. Accessed September 30, 2020. <https://www.oecd.org/environment/waste/background-paper-sustainable-plastics-from-a-chemicals-perspective-considerations-and-criteria.pdf>

<sup>5</sup> Organization for Economic Cooperation and Development (OECD). "OECD Global Forum on Environment Focusing on Sustainable Materials Management." OECD Environment Directorate. 2010. Accessed October 15, 2020. <http://www.oecd.org/env/waste/46111789.pdf>.

<sup>6</sup> ECHA. (n.d.), "Candidate List of substances of very high concern for Authorisation - ECHA," <https://echa.europa.eu/candidate-list-table> (accessed October 7, 2020).

<sup>7</sup> ChemSec. (n.d.), "SIN List," <https://sinlist.chemsec.org/> (accessed October 7, 2020).

<sup>8</sup> "Sales Struggle in 2019." *Floor Covering Weekly*, July 27, 2020. <https://bt.editionsbyfry.com/publication/?i=667949&p=1&pp=1&view=issueViewer>.

<sup>9</sup> "Sales Struggle in 2019." *Floor Covering Weekly*, July 27, 2020. <https://bt.editionsbyfry.com/publication/?i=667949&p=1&pp=1&view=issueViewer>.

<sup>10</sup> Pharos. "PVC-Free Resilient Flooring (Homogeneous)." Accessed September 17, 2020. <https://pharosproject.net>.

<sup>11</sup> "Declare Label - Crossville Porcelain Tiles." Accessed September 17, 2020. <https://declare.living-future.org/products/crossville-porcelain-tiles>; "Declare Label - Marmoleum Sheet." Accessed September 17, 2020. <https://declare.living-future.org/products/marmoleum-sheet>; "Declare Label - Aspecta Five Luxury Vinyl Tile." Accessed September 17, 2020. <https://declare.living-future.org/products/aspecta-five-luxury-vinyl-tile>; "Declare Label - Artistek by Metroflor American Plank & Tile Plus Luxury Vinyl Tile." Accessed September 17, 2020. <https://declare.living-future.org/products/artistek-by-metroflor-american-plank-tile-plus-luxury-vinyl-tile>; "Declare Label - Natural Wood Flooring/Walls/Ceilings." Accessed September 17, 2020. <https://declare.living-future.org/products/natural-wood-flooring-walls-ceilings>; "Declare Label - Migrations BBT and Striations BBT with Diamond 10 Technology Coating." Accessed September 17, 2020. <https://declare.living-future.org/products/migrations-bbt-and-striations-bbt-with-diamond-10-technology-coating>; "Declare Label - Ava Sheet Vinyl (SV)." Accessed September 17, 2020. <https://declare.living-future.org/products/ava-sheet-vinyl-sv>.

<sup>12</sup> "Vinyl Flooring Market Size, Share, Trends | Industry Report, 2019-2025." Accessed September 17, 2020. <https://www.grandviewresearch.com/industry-analysis/vinyl-flooring-market>.

Floor Covering News. "Scoring Flooring: Industry Stats for 2019," June 30, 2020. <https://www.fcnews.net/2020/06/scoring-flooring-industry-stats-for-2019/>.

<sup>13</sup> "MFA Formalizes Nomenclature for Rigid Core Vinyl Products." Accessed September 16, 2020. <https://www.floordaily.net/floorfocus/mfa-formalizes-nomenclature-for-rigid-core-vinyl-products>.

<sup>14</sup> Moore, Lauren. "One Year In." *Floor Covering Weekly*, February 20, 2018. <https://www.floorcoveringweekly.com/main/business-builder/one-year-in-21321>.

<sup>15</sup> Pharos. "Multilayer Resilient Flooring (WPC)." Accessed September 16, 2020. <https://pharosproject.net/common-products/2203433>.

<sup>16</sup> "Benefits of Resilient." Congoleum. Accessed June 10, 2019. <https://www.congoleum.com/benefits-of-resilient/>.

<sup>17</sup> Healthy Building Network. (n.d.), "Common Products," Pharos, <https://pharosproject.net/common-products> (accessed October 7, 2020).

- <sup>18</sup> Vallette, Jim. "Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe," March 2019. <https://healthybuilding.net/reports/18-chlorine-building-materials-project>; Vallette, Jim. "Chlorine & Building Materials Project: Phase 2 Asia Including Worldwide Findings," March 2019. <https://healthybuilding.net/reports/20-chlorine-building-materials-project-phase-2-asia-including-worldwide-findings>.
- <sup>19</sup> ECHA. (n.d.), "Candidate List of substances of very high concern for Authorisation - ECHA," <https://echa.europa.eu/candidate-list-table> (accessed October 7, 2020).
- <sup>20</sup> ChemSec. (n.d.), "SIN List," <https://sinlist.chemsec.org/> (accessed October 7, 2020).
- <sup>21</sup> Vallette, Jim. "Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe," March 2019. <https://healthybuilding.net/reports/18-chlorine-building-materials-project>
- <sup>22</sup> Pharos. "Polyethylene Terephthalate (PET)." Accessed September 15, 2020. <https://pharosproject.net/chemicals/2011623#process-chemistry-panel>.
- <sup>23</sup> Tian, Dong, Gary A. Sigel, Fang Qiao, Rebecca L. Winey, and Jeffrey S. Ross. Polyester binder for flooring products. United States US20080081882A1, filed October 2, 2006, and issued April 3, 2008. <https://patents.google.com/patent/US20080081882A1/en>; Davies, Mary Kate, and Dong Tian. Biobased plasticizer and surface covering employing the same. United States US8609884B2, filed March 19, 2012, and issued December 17, 2013. <https://patents.google.com/patent/US8609884B2>; National Center for Biotechnology Information. (n.d.), "PubChem Annotation Record for 1,3-Propanediol, Source: Hazardous Substances Data Bank (HSDB)," <https://pubchem.ncbi.nlm.nih.gov/source/hsdb/8263#section=Methods-of-Manufacturing> (accessed October 6, 2020).
- <sup>24</sup> Tian, Dong, Gary A. Sigel, Fang Qiao, Rebecca L. Winey, and Jeffrey S. Ross. Polyester binder for flooring products. United States US20080081882A1, filed October 2, 2006, and issued April 3, 2008. <https://patents.google.com/patent/US20080081882A1/en>; Bio-based News. "U.S.A.: World's First Propanediol Production from Corn Sugar Opened - Bio-Based News -," August 13, 2007. <http://news.bio-based.eu/u-s-a-worlds-first-propanediol-production-from-corn-sugar-opened/>; "Bio-Flooring: Striations BBT, Migrations BBT." Armstrong Flooring. Accessed September 18, 2020. <https://www.armstrongflooring.com/pdbupimages-flr/219054.pdf>.
- <sup>25</sup> Rossi, Mark S., and Anne Blake. "The Plastics Scorecard (Version 1.0)." Clean Production Action, July 1, 2014. <https://www.bizngo.org/sustainable-materials/plastics-scorecard>; *Compilation of Air Pollutant Emission Factors*. 5th ed. Vol. Volume I: Stationary Point and Area Sources, Part Two. United States Environmental Protection Agency, 1995. <https://nepis.epa.gov/Exe/ZyPDF.cgi/20014A2W.PDF?Dockey=20014A2W.PDF>; Franklin Associates. "Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors," August 2011; Lithner, Delilah, Åke Larsson, and Göran Dave. "Environmental and Health Hazard Ranking and Assessment of Plastic Polymers Based on Chemical Composition." *Science of The Total Environment* 409, no. 18 (August 15, 2011): 3309–24. <https://doi.org/10.1016/j.scitotenv.2011.04.038>; Pharos. "Polyethylene Terephthalate (PET)." Accessed September 15, 2020. <https://pharosproject.net/chemicals/2011623#process-chemistry-panel>; Vallette, Jim. "Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe," March 2019. <https://healthybuilding.net/reports/18-chlorine-building-materials-project>; Vallette, Jim. "Chlorine & Building Materials Project: Phase 2 Asia Including Worldwide Findings," March 2019. <https://healthybuilding.net/reports/20-chlorine-building-materials-project-phase-2-asia-including-worldwide-findings>; Healthy Building Network. (n.d.), "Common Products," Pharos, <https://pharosproject.net/common-products> (accessed October 7, 2020).
- <sup>26</sup> Perkins + Will. "Healthy Environments: What's new (and what's not) with PVC". Accessed online on October 19, 2020. [https://s3.amazonaws.com/hbnweb.dev/uploads/files/KtNF\\_PerkinsWill\\_PVC\\_2015\\_Whitepaper\\_2.pdf](https://s3.amazonaws.com/hbnweb.dev/uploads/files/KtNF_PerkinsWill_PVC_2015_Whitepaper_2.pdf); VinylPlus. "Vinylplus progress report 2020". Accessed online on October 19, 2020. [https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020\\_EN\\_sp.pdf](https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020_EN_sp.pdf); Healthy Building Network. (n.d.), "Common Products," Pharos, <https://pharosproject.net/common-products> (accessed October 7, 2020); J. Eagle. (10 May 2015), "Study suggests biodegradation-promoting additives for degrading PE and PET are not effective," *Food Navigator*, <https://www.foodnavigator.com/Article/2015/05/11/Biodegradation-additives-for-degrading-PE-and-PET-not-effective> (accessed September 28, 2020); "BPI Position on Degradable Additives." (n.d.), *Biodegradable Products Institute*, [https://bpiworld.org/BPI Position on Degradable Additives/](https://bpiworld.org/BPI%20Position%20on%20Degradable%20Additives/) (accessed September 28, 2020); Pharos. "Polyethylene Terephthalate (PET)." Accessed September 15, 2020. <https://pharosproject.net/chemicals/2011623#process-chemistry-panel>; Vallette, Jim. "Post-Consumer

---

Polyvinyl Chloride In Building Products.” Healthy Building Network, July 2015.

<https://healthybuilding.net/reports/11-post-consumer-polyvinyl-chloride-in-building-products>.

<sup>27</sup> “Tarkett Sustainability Journey: Our Progress in 2019.” Tarkett. Accessed September 22, 2020.

[https://www.tarkett.com/sites/default/files/2020%20DDR/UK\\_KeyFigures.pdf](https://www.tarkett.com/sites/default/files/2020%20DDR/UK_KeyFigures.pdf).

<sup>28</sup> Vinyl Plus. (2020), Progress Report 2020. (p. 40),

[https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020\\_EN\\_sp.pdf](https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020_EN_sp.pdf).

<sup>29</sup> Vinyl Sustainability Council. (n.d.), *Our Sustainable Journey: 2015-2019.*,

<https://vantagevinyl.com/progress-report/> (accessed September 28, 2020).

<sup>30</sup> Based on HBN’s Common Product Research, vinyl tile and sheet contain about 0.7-1.0 kg of PVC per square meter of flooring. WPC flooring contains about 2.8 kg of PVC per square meter of flooring. PVC-free resilient flooring contains about 0.9 kg of polymer per square meter of flooring.

<sup>31</sup> “ChemFORWARD.” (n.d.), *ChemFORWARD*, <https://www.chemforward.org> (accessed October 19, 2020).; J. P. Harmon and R. Otter. (2018), “Green Chemistry and the Search for New Plasticizers,” *ACS Sustainable Chemistry & Engineering*, Vol. 6/2, pp. 2078–2085, American Chemical Society, <https://doi.org/10.1021/acssuschemeng.7b03508>.

<sup>32</sup> R. Krock and S. Tarnell. (2015), “Recycling as a Sustainability Practice in the North American Vinyl Industry,” <https://www.vinylinfo.org/wp-content/uploads/2019/01/Krock-Vinyl-Institute-Recycled-Vinyl-as-a-Sustainability-Practice.pdf>.

<sup>33</sup> Vallette, Jim. “Post-Consumer Polyvinyl Chloride In Building Products.” Healthy Building Network, July 2015. <https://healthybuilding.net/reports/11-post-consumer-polyvinyl-chloride-in-building-products>.

<sup>34</sup> Ehrlich, Brent. “New PVC-Free Resilient Flooring Options.” BuildingGreen, July 26, 2018.

<https://www.buildinggreen.com/product-review/new-pvc-free-resilient-flooring-options>.

<sup>35</sup> M. Filella. (2020), “Antimony and PET bottles: Checking facts,” *Chemosphere*, Vol. 261, p. 127732, <https://doi.org/10.1016/j.chemosphere.2020.127732>.

<sup>36</sup> J. Eagle. (10 May 2015), “Study suggests biodegradation-promoting additives for degrading PE and PET are not effective,” *Food Navigator*,

<https://www.foodnavigator.com/Article/2015/05/11/Biodegradation-additives-for-degrading-PE-and-PET-not-effective> (accessed September 28, 2020).; “BPI Position on Degradable Additives.” (n.d.),

*Biodegradable Products Institute*, <https://bpiworld.org/BPI-Position-on-Degradable-Additives/> (accessed September 28, 2020).

<sup>37</sup> Healthy Building Network. (n.d.), “Common Products,” *Pharos*, <https://pharosproject.net/common-products> (accessed October 7, 2020).

<sup>38</sup> S. D. Mitro et al. (2016), “Consumer Product Chemicals in Indoor Dust: A Quantitative Meta-analysis of U.S. Studies,” *Environmental Science & Technology*, Vol. 50/19, pp. 10661–10672,

<https://doi.org/10.1021/acs.est.6b02023>.; C. Bi et al. (2018), “Phthalates and organophosphates in settled dust and HVAC filter dust of U.S. low-income homes: Association with season, building characteristics, and childhood asthma.” *Environment International*, Vol. 121, pp. 916–930, <https://doi.org/10.1016/j.envint.2018.09.013>.

<sup>39</sup> Rossi, Mark S., and Anne Blake. “The Plastics Scorecard (Version 1.0).” Clean Production Action, July 1, 2014. <https://www.bizngo.org/sustainable-materials/plastics-scorecard>.

<sup>40</sup> Filella, Montserrat. “Antimony and PET Bottles: Checking Facts.” *Chemosphere* 261 (December 1, 2020): 127732. <https://doi.org/10.1016/j.chemosphere.2020.127732>.

<sup>41</sup> Armstrong Flooring. (2019), “Environmental Product Declaration: Biobased Tile with Diamond 10 Technology Coating,” <https://www.armstrongflooring.com/pdbupimages-flr/220749.pdf>.; Resilient Floor Covering Institute. (2019), “Environmental Product Declaration: Rigid Core Flooring,” <https://rfci.com/wp-content/uploads/2019/01/103.1-RFCI-EPD-Rigid-Core-Flooring.pdf>.; Resilient Floor Covering Institute. (2019), “Environmental Product Declaration: Vinyl Composition Tile,” <https://rfci.com/wp-content/uploads/2019/01/105.1-RFCI-EPD-Vinyl-Composition-Tile.pdf>.; Resilient Floor Covering Institute. (2019), “Environmental Product Declaration: Vinyl Tile,” <https://rfci.com/wp-content/uploads/2019/01/106.1-RFCI-EPD-Vinyl-Tile.pdf>.

<sup>42</sup> Vinyl Sustainability Council. (2019), *Our Sustainable Journey: 2015-2019.*, <https://vantagevinyl.com/progress-report/> (accessed September 28, 2020).

- On&On Floor Recycling Program.” Armstrong Flooring, 2016.  
<https://www.armstrongflooring.com/content/dam/armstrongflooring/commercial/north-america/Sustainability/Recycling-Program-Brochure.pdf>.; “Tarkett Sustainability Journey: Our Progress in 2019.” Tarkett. Accessed September 22, 2020.  
[https://www.tarkett.com/sites/default/files/2020%20DDR/UK\\_KeyFigures.pdf](https://www.tarkett.com/sites/default/files/2020%20DDR/UK_KeyFigures.pdf).; “Progress Report 2020.” Vinyl Plus, 2020.  
[https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020\\_EN\\_sp.pdf](https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020_EN_sp.pdf).
- <sup>43</sup> Thomas, Pete. “Flooring: a resource efficiency action plan” Sept 2010. Accessed online on October 18, 2020. [http://www.wrap.org.uk/sites/files/wrap/Flooring\\_REAP.pdf](http://www.wrap.org.uk/sites/files/wrap/Flooring_REAP.pdf)
- <sup>44</sup> M. Zhang et al. (2015), “Dioxins and polyvinylchloride in combustion and fires,” *Waste Management & Research*, Vol. 33/7, pp. 630–643, SAGE Publications Ltd STM, <https://doi.org/10.1177/0734242X15590651>.
- <sup>45</sup> NITE. GHS Japan's GHS Classifications for Dioxins CHIRP ID C001-180-63A. Accessed online on October 19, 2020. [https://www.nite.go.jp/chem/english/ghs/ghs\\_index.html](https://www.nite.go.jp/chem/english/ghs/ghs_index.html)
- <sup>46</sup> Avakian Maureen D et al. (2002), “The origin, fate, and health effects of combustion by-products: a research framework.” *Environmental Health Perspectives*, Vol. 110/11, pp. 1155–1162, Environmental Health Perspectives, <https://doi.org/10.1289/ehp.021101155>.
- <sup>47</sup> Perkins + Will. “Healthy Environments: What's new (and what's not) with PVC”. Accessed online on October 19, 2020.  
[https://s3.amazonaws.com/hbnweb.dev/uploads/files/KINF\\_PerkinsWill\\_PVC\\_2015\\_Whitepaper\\_2](https://s3.amazonaws.com/hbnweb.dev/uploads/files/KINF_PerkinsWill_PVC_2015_Whitepaper_2).
- <sup>48</sup> K. Sovová et al. (2008), “A study of thermal decomposition and combustion products of disposable polyethylene terephthalate (PET) plastic using high resolution fourier transform infrared spectroscopy, selected ion flow tube mass spectrometry and gas chromatography mass spectrometry,” *Molecular Physics*, Vol. 106/9–10, pp. 1205–1214, Taylor & Francis, <https://doi.org/10.1080/00268970802077876>.
- <sup>49</sup> Vallette, Jim. “Post-Consumer Polyvinyl Chloride In Building Products.” Healthy Building Network, July 2015. <https://healthybuilding.net/reports/11-post-consumer-polyvinyl-chloride-in-building-products>.
- <sup>50</sup> D. S. Achilias et al. (2012), “Recent advances in the chemical recycling of polymers (PP, PS, LDPE, HDPE, PVC, PC, Nylon, PMMA),” *Material Recycling-Trends and Perspectives*, InTechOpen, <https://cdn.intechopen.com/pdfs-wm/32560.pdf>.
- <sup>51</sup> Petchwattana, Nawadon, Sirijutaratana Covavisaruch, and Jakkid Sanetuntikul. “Recycling of Wood–Plastic Composites Prepared from Poly(Vinyl Chloride) and Wood Flour.” *Construction and Building Materials* 28, no. 1 (March 1, 2012): 557–60. <https://doi.org/10.1016/j.conbuildmat.2011.08.024>.
- <sup>52</sup> Healthy Building Network. (n.d.), “Ethylene glycol,” *Pharos*, <https://pharosproject.net/chemicals/2008166#hazards-panel> (accessed October 2, 2020).
- <sup>53</sup> J. Scheirs and T. E. Long. (2005), *Modern Polyesters: Chemistry and Technology of Polyesters and Copolyesters*, John Wiley & Sons.
- <sup>54</sup> A. Sangalang, S. Seok and D. H. Kim. (2016), “Practical Design of Green Catalysts for PET Recycling and Energy Conversion,” *Advanced Catalytic Materials - Photocatalysis and Other Current Trends*, InTechOpen, <https://doi.org/10.5772/62041>.
- <sup>55</sup> A. B. Raheem et al. (2019), “Current developments in chemical recycling of post-consumer polyethylene terephthalate wastes for new materials production: A review,” *Journal of Cleaner Production*, Vol. 225, pp. 1052–1064, <https://doi.org/10.1016/j.jclepro.2019.04.019>.
- <sup>56</sup> Minamata Convention on Mercury. “Parties and Signatories: Status of Signature, and ratification, acceptance, approval or accession” Accessed on September 30, 2020.  
<http://www.mercuryconvention.org/Countries/Parties/tabid/3428/language/en-US/Default.aspx> Silva, Rafaela Rodrigues da, Jeffer Castelo Branco, Silvia Maria Tage Thomaz, and Augusto Cesar. “Minamata Convention: Analysis of the Socio-Environmental Impacts of a Long-Term Solution.” *SciELO Analytics, Saude Debate*, 41 (June 2017): 50–62. Accessed October 2, 2020. [http://www.scielo.br/scielo.php?pid=S0103-11042017000600050&script=sci\\_arttext&tlng=en](http://www.scielo.br/scielo.php?pid=S0103-11042017000600050&script=sci_arttext&tlng=en)
- <sup>57</sup> Vallette, Jim. “Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe,” March 2019. Accessed October 2, 2020. <https://healthybuilding.net/reports/18-chlorine-building-materials-project>;
- <sup>58</sup> Chemsafety Pro. “Phthalates” . Accessed October 2, 2020.  
[https://www.chemsafetypro.com/Topics/EU/REACH\\_annex\\_XVII\\_phthalates\\_restriction.html](https://www.chemsafetypro.com/Topics/EU/REACH_annex_XVII_phthalates_restriction.html)

<sup>59</sup> ECHA. "The Committee for Risk Assessment (RAC) adopted two opinions on the restriction proposal on the four phthalates (DEHP, DBP, DIBP and BBP) in articles and on TDFAs . The Socio-economic Analysis Committee (SEAC) agreed its draft opinions on the same proposals" March 21, 2017. Accessed October 2, 2020.

[https://echa.europa.eu/documents/10162/23012100/news\\_annex\\_racseac\\_1705\\_en.pdf/be17cae7-9a14-4d6f-db04-0c8328855b5c](https://echa.europa.eu/documents/10162/23012100/news_annex_racseac_1705_en.pdf/be17cae7-9a14-4d6f-db04-0c8328855b5c)

ECHA. "Entry 51 ANNEX XVII TO REACH – Conditions of restriction." 2018. Accessed October 2, 2020. [https://echa.europa.eu/documents/10162/13641/51\\_10503\\_en.pdf/aaa92146-a005-1dc2-debe-93c80b57c5ee](https://echa.europa.eu/documents/10162/13641/51_10503_en.pdf/aaa92146-a005-1dc2-debe-93c80b57c5ee)

<sup>60</sup> Miller, Gillian, M. Belliveau, M. Schade, B. Walsh. "Success! – Home improvement retailers follow through on commitments to remove phthalates from flooring" June 29, 2019. Accessed October 2, 2020. <https://saferchemicals.org/2019/06/27/success-home-improvement-retailers-follow-through-on-commitments-to-remove-phthalates-from-flooring/>

<sup>61</sup> "Recovinyl About Us." (n.d.), *Recovinyl*, <https://www.recovinyl.com/about-us> (accessed October 19, 2020).

<sup>62</sup> VinylPlus. "Progress Report 2020". Accessed October 2, 2020.

[https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020\\_EN\\_sp.pdf](https://vinylplus.eu/uploads/images/progreport2020/VinylPlus%20Progress%20Report%202020_EN_sp.pdf)

<sup>63</sup> reVinylFloor Charter. 2018. Accessed online on October 18, 2020 at [https://5c2664ad-92c3-4bf0-bc5e-24ea23bfaa1b.filesusr.com/ugd/2eb778\\_a8aa227c0efd4d3e9bad421b2d69f2dc.pdf](https://5c2664ad-92c3-4bf0-bc5e-24ea23bfaa1b.filesusr.com/ugd/2eb778_a8aa227c0efd4d3e9bad421b2d69f2dc.pdf).

The weight of European production and supply of vinyl flooring was estimated using square footage information from reVinylFloor Charter ("The European production and supply of PVC flooring is estimated to be 75 million m<sup>2</sup> for 2016") and the median weight per area for Luxury Vinyl Tile, which is about 0.94 pounds per square foot. This was used to estimate the percentage recycled. Different types of vinyl flooring have different typical weight per area. This calculation is intended to give an estimate of the scale of flooring that is recycled.